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STATUS REPORT ON TRISERVICE DATA BASE EXTENSION

OF PROGRAM MISSILE

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ABSTRACT

A status report is given on the development of PROGRAM MISSILE[1,2], which is a comprehensive aerodynamic prediction code capable of computing the longitudinal and lateral stability and control characteristics of cruciform body-tail and canard (wing)-body-tail tactical missiles. The methodology used is described and the planned data base extension is outlined. The rational modeling concepts used to extend the fin-body data base to general body-tail and canard-body-tail missiles are presented.

INTRODUCTION

Despite considerable progress in recent years, there still exists a need for general reliable predictive methods for the forces and moments acting on missiles for use in design studies over the entire speed range from subsonic to hypersonic flow, particularly for high angles of attack. The approaches to predictive methodology which seem most applicable to this task include: (1) data base, (2) rational modeling, (3) paneling methods, and (4) computational fluid dynamics.

There is little question that computational fluid dynamics (CFD), which involves numerical solutions of the basic flow equations will become more important in the future. However, there are considerable obstacles to be overcome before such powerful techniques will be available for design studies. Computers are not big, fast, or cheap enough and will not be for many years. Turbulence modeling has not reached the stage where it can be confidently applied to general flow problems. Hence, although this work will and should be continued, the designer must cast around for other means to satisfy his needs.

In the data-base approach to predictive methods development, correlations or other means of rationally assembling experimental data are used to produce predictive techniques. In these, the ranges of geometry and flow parameters are systematically investigated in order to give the best possible foundation for correlation and interpolation work. The data-base approach has the considerable advantage that all of the flow phenomena affecting vehicle performance are accounted for, whether or not the details are specifically recognized on a physical basis. However, the approach is limited to the geometry and flow ranges of the data. This means that while interpolation is a fairly certain process, extrapolation is not. Thus, in order to have wide generality, the data base itself has to be very wide and

this can involve much testing. For a generalized missile with forward and aft lifting surfaces, the cost would be prohibitive.

The idea of rational modeling is to conceptualize the primary phenomena affecting vehicle behavior (vortices, wakes, attached flow) and to stimulate these with flow models based on classical potential and viscous fluid-dynamic theory. This approach is less configuration and flow parameter limited than the data-base approach, and it does permit extrapolation. However, the main disadvantage is that not all of the flow phenomena affecting vehicle behavior may be properly recognized or understood. Hence, the modeling of phenomena may be imprecise and not even complete. It is only necessary to consider, for example, a vapor-screeen photograph of the flow around a complex missile configuration and compare this with the classical fluid-dynamic models available to recognize the difficulties inherent in rational modeling.

For high angle-of-attack aerodynamics, we suggest that the best approach to method development is a combination of data base and rational modeling. In such an approach the rational modeling predictions are modified empirically or semiempirically by comparing them with and matching them to the data. This should, given better accounting of the phenomena affecting vehicle behavior, result in better precision. What is particularly important is that the applicability of the data base can be extended orders of magnitude beyond its original configuration space by rational modeling. Inputs from experimental data ensure that the shortcomings of the rational models will be supplemented by the systematic experimental data. Of course, the use of experimental data to modify a predictive technique is not new. What is new here is the emphasis on the combination of a powerful systematic data base generated over extensive ranges of geometry and flow parameters, coupled with the rational modeling. This is the approach which has been used to produce PROGRAM MISSILE. The following section briefly describes the combination of data base and rational modeling used in PROGRAM MISSILE. The concluding section outlines the planned TRISERVICE effort to extend the available data base.

DESCRIPTION OF THE PRESENT METHOD

GENERAL CONSIDERATIONS

A typical configuration considered is shown in Figure 1 in a flow at an angle of attack. Also shown is the general vortex flow field produced by such a configuration. The configuration consists of the following components:

1. Forebody section - up to the first set of lifting surfaces,

2. Canard or wing section - over the length of the root chord of the first set of lifting surfaces,

3. Afterbody section - between the first and second set of lifting surfaces,

4. Tail section - behind the root-chord leading edge of the rear set of lifting surfaces.

Although the method was designed specifically for configurations such as the one shown in Figure 1, the computational procedures are such that it will accommodate less geometrically-complex configurations as well, such as a body-alone or a body-tail design.

Determination of the loads (forces and moments) on the various components of a missile at an arbitrary combination of angle of attack, roll angle, and control surface deflection in a flow field requires accurate modeling of several aerodynamic effects. These effects include that due to angle of attack (i.e., potential lift), interference among the various components, such as panel-panel interference, viscosity, and the loading induced by the external vortex field. This vorticity originates in the boundary layer of both the body and the fins. At higher angles of attack these various effects result in the loads on the missile exhibiting strong nonlinear behavior. Recent comprehensive reviews of this nonlinear behavior are given in References 3 and 4.

FOREBODY SECTION

PROGRAM MISSILE is restricted to bodies with circular cross sections. Furthermore, it is assumed that the flow over the forebody is symmetrical about the plane formed by the body axis and the wind velocity vector. Thus, the program is not likely to be accurate for very long forebodies at high angles of attack in subsonic flow.

The normal force and pitching-moment on the forebody are found using a slightly modified version of Allen's crossflow theory together with Jorgensen's compilation of crossflow drag coefficients[5]. The vorticity shed by the forebody is modeled by two symmetrical Rankine vortices with large solid-body cores. The locations and strengths of the vortices at the leading edge of the first finned section are obtained from a table. The table is composed of available data for angles of attack less than 20° and computer generated results using vortex cloud theory[6] for angles of attack greater than 20°. Boundary conditions for the computer program were modified heuristically to account for the effects of compressibility on the vortex strengths[1,3].

FINNED SECTION (CANARD, WING OR TAIL)

Calculation of fin loads by PROGRAM MISSILE for arbitrary roll angles, fin deflection and vorticity fields depends on five things:

1. a model of vorticity field; i.e., the forebody model of the previous section or the afterbody model of the next section;

2. a method for computing the average angle of attack, $(\Delta\alpha_{eq})_{v_i}$, induced on the fins by the vorticity field;

3. a data base for fin-body combinations with no vortices present for $a/s_m = 0.5$;

4. a wing-alone data base;

5. an addition theorem to account for the effects of vortices and $a/s_m \neq 0.5$.

We will restrict the discussion to the computation of fin normal force. The methods used to compute body force and center of pressure and fin center of pressure are described in detail in Reference 1 and 7.

Vortex Effects

The vorticity field at each cross section of the finned section is assumed to be the same as that at the leading edge of the fin root chord (beginning of the section). Various vapor-screen studies and limited vortex tracking computations indicate that this is a reasonable assumption for the distributed vortex field typical of missiles. We plan to check this assumption further using a new Euler code which is capable of representing distributed vortex fields accurately[8,9]. The average angle of attack induced on the fins by the computed vorticity field is obtained by reverse flow theory[1,10].

Data Base

The present PROGRAM MISSILE data base for a fin-body combination with $a/s_m = 0.5$ was developed from body-tail data obtained by J. E. Fidler[11] and supplied to us by Dr. Donald Spring of the Army Missile Command. The parameters of the data base are given in a later section. Vortex effects were removed from the data base using the models described above. The method used in PROGRAM MISSILE to account for vortex effects and $a/s_m \neq 0.5$ (addition theorem) requires a wing-alone data base. Such a data base which would be complementary to the Fidler data base was not available. However, sufficient systematic data were available to guide construction of the necessary base by interpolation and extrapolation.

Addition Theorem

The method used in PROGRAM MISSILE to account for vortex effects and $a/s_m \neq 0.5$ is based on wing-alone data and the idea of an equivalent angle of attack. The notion is to determine the coefficient of normal force acting on the fin in the presence of a body, $\hat{C}_{N_{F_i(B)}}$, with $a/s_m = 0.5$ and no vortices present for the body angle of attack, α_c, and the fin roll angle, ϕ_i, of interest. As shown in Figure 2, this value of $\hat{C}_{N_{F_i(B)}}$ is used to determine an equivalent wing-alone angle of attack, $\alpha_{eq,p}$. A change in the equivalent angle of attack is computed and added to $\alpha_{eq,p}$. Then the wing-alone curve is used to obtain the desired fin normal force coefficient, $C_{N_{F_i(B)}}$.

AFTERBODY SECTION

The flow over the afterbody section is computed in two different ways depending upon the version of PROGRAM MISSILE used. In both versions the trailing vorticity from each fin is assumed to be fully rolled up into one or two Rankine vortices depending upon the spanwise location of the center of pressure. In MISSILE1, the afterbody vorticity is modeled as two asymmetric Rankine vortices whose positions are computed by slender-body tracking. The positions of the fin vortices and forebody vortices (if present) are computed

at the same time. The mutual interactions of all of the vortices are accounted for. The method used to determine the changing strengths of the afterbody vortices is a heuristic one based on crossflow drag theory and the vortex impulse theorem[7].

In MISSILE2, the afterbody vorticity is modeled by dividing the afterbody into axial segments and allowing each segment to shed a Rankine vortex on each side of the body. The strengths and positions of the newly shed vortices are determined from the computed pressure and velocity distributions on the body. This "vortex cloud" method, while requiring greater computing time, does allow the program to represent the afterbody wake more closely when asymmetric conditions are present.

PLANNED EXTENSION

PARAMETER RANGE

There are two parts to the planned extension of the PROGRAM MISSILE data base: (1) the wing-alone and fin-on-body parameter range will be extended in aspect ratio and Mach number, and (2) a comprehensive data base will be obtained for fin deflection. The present and planned parameter range is shown in Figure 3. The wing-alone data base is being obtained under separate contract.* The angle of attack range for the TRISERVICE tests will be 0-45° and the fin deflection range will be -40° to +40°. All the fins will be clipped delta planforms with the taper ratio ranging from 0 to 1. The fin deflection tests will be confined to the $1 \leq A\!\!R \leq 4$ range.

An important aspect of the tests will be the determination of hinge moments. To make the data systematic with respect to airfoil section effects and to make it easier to model the fins, double wedge airfoils with constant thickness to chord ratio over the planform will be used. The control fins will have the same thickness to chord ratio of 0.06.

MODEL AND WIND TUNNELS

The model to be used is an advanced remote control rig developed by NASA/LRC and MICRO CRAFT, Inc. It is capable of remote roll with the sting held fixed and each of four fins can be deflected independently. Two sets of fins can be mounted and the deflecting fins can be positioned in three different locations corresponding to canard, wing or tail control. For the planned tests, only the tail position will be used to generate the data base. In addition to the main balance, each fin will have its own three-component balance.

In order to cover the entire Mach number range, testing will be conducted in the NASA/LRC Unitary Wind Tunnel, section 2, for $M_\infty = 2\text{-}4.5$ and in

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*The wing-alone work is being coordinated by the Army Research Office under direction of Dr. Robert Singleton. Other sponsors are NAVAIR, NASA/Ames Research Center, NASA/Langley Research Center, and the Army Missile Command.

The NASA/ARC 6- by 6-Foot Supersonic Wind Tunnel for M_∞ = 0.6-2. Testing is expected to begin in early September, 1981.

DATA HANDLING

The data base to be obtained will consist of approximately one million words. This is too large a data base to be stored in core. Hence, we plan to store the data base on tape together with the source code for PROGRAM MISSILE. When a new user wishes to use the code, he would obtain a copy of that tape and store the source code and data base on disk files. When he wishes to use the code for a particular configuration, a preprocessor would be used to interpolate in the data base and construct only those tables needed for the computation. Then the main program would use those tables to compute the aerodynamic characteristics of that configuration.

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SYMBOLS

a	body radius
$\mathcal{R}$	aspect ratio
$C_{N_{F_i(B)}}$	normal-force coefficient for fin i
$\hat{C}_{N_{F_i(B)}}$	normal-force coefficient for fin i if a/s_m = 0.5, no vortices are present and no fins are deflected
C_{N_W}	normal-force coefficient for wing-alone
M_∞	free-stream Mach number
s_m	semispan of fin on body
α	wing-alone angle of attack
α_c	included angle of attack, angle between body axis and free-stream velocity vector
α_{eq}	equivalent angle of attack
$\alpha_{eq,p}$	equivalent angle of attack corresponding to $\hat{C}_{N_{F_i(B)}}$
$\Delta\alpha_{eq}$	increment in equivalent angle of attack

$(\Delta\alpha_{eq})_{v_i}$ increment in equivalent angle of attack due to presence of vortices

δ_j angle of deflection of fin j

ϕ_i bank angle of fin i, measured clockwise from right horizontal position

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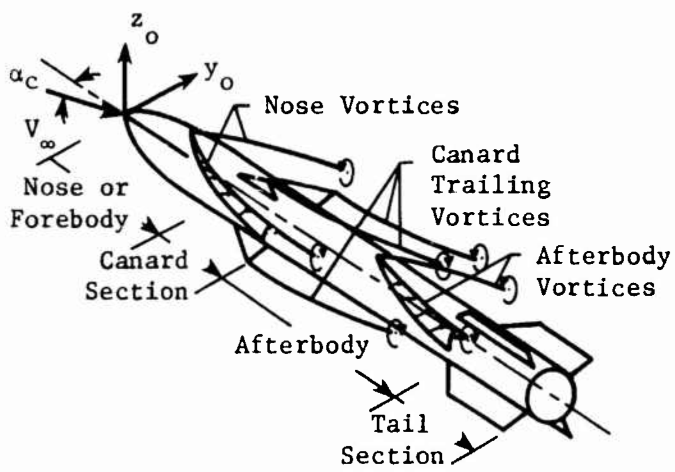


Figure 1 Banked canard-cruciform missile at angle of attack showing typical vortex field

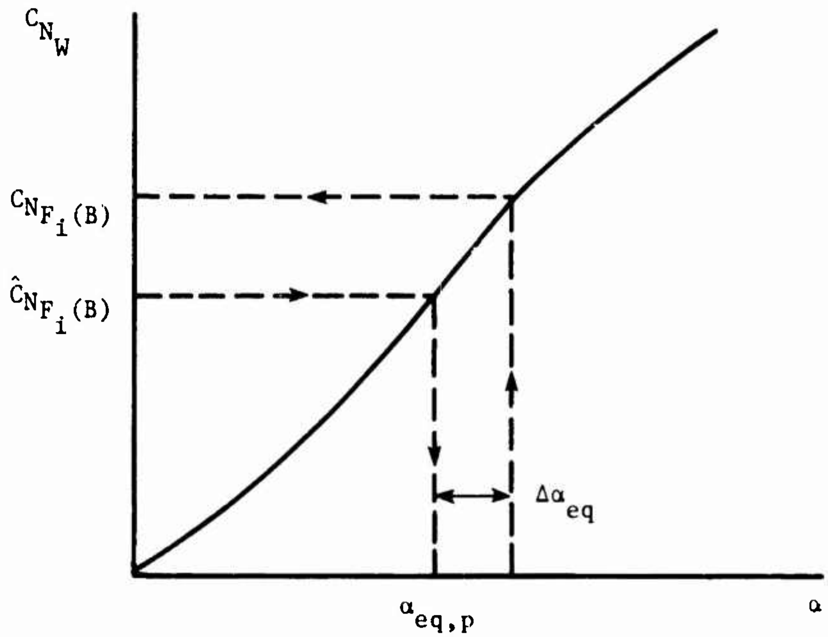
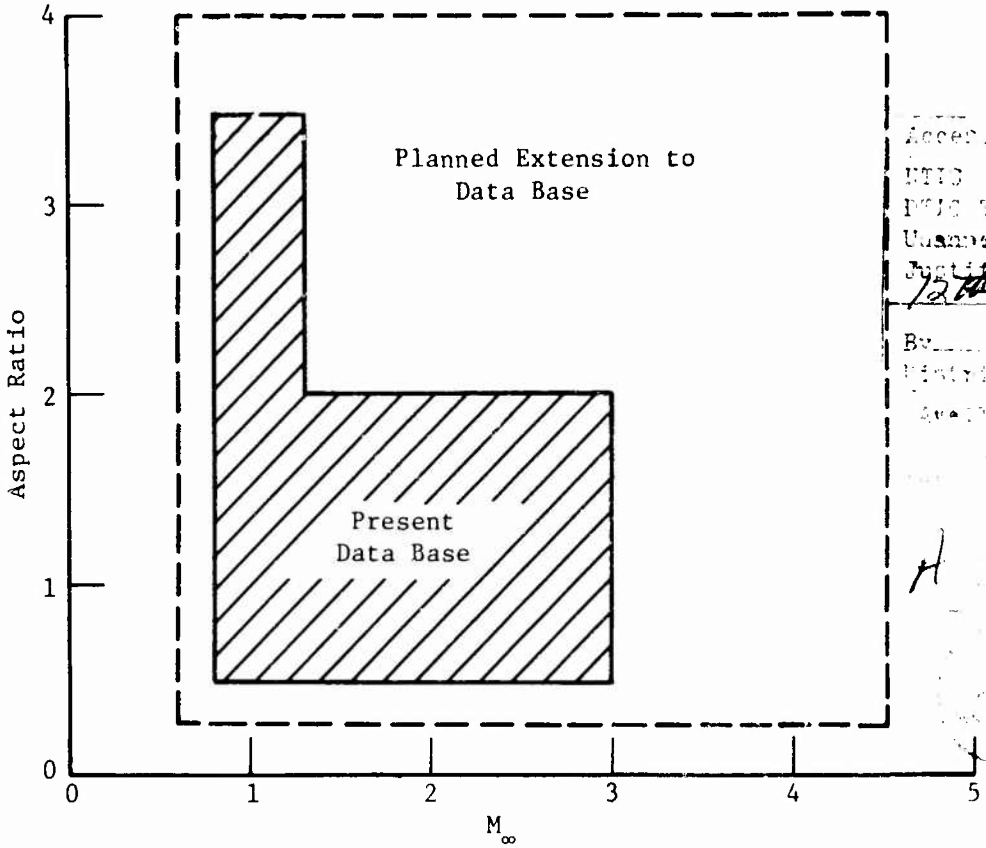


Figure 2 Illustration of equivalent angle of attack concept



(a) Aspect-ratio/Mach-number range

AR \ λ	0	1/2	1
1/4		X	
1/2	X	X	X
1		X	
2	X	X	X
4		X	

Wing Base (AR = 1/4, 1/2, 1)

Control Base (AR = 1, 2, 4)

(b) Aspect-ratio/taper-ratio range

Figure 3 Planned data base range for PROGRAM MISSILE